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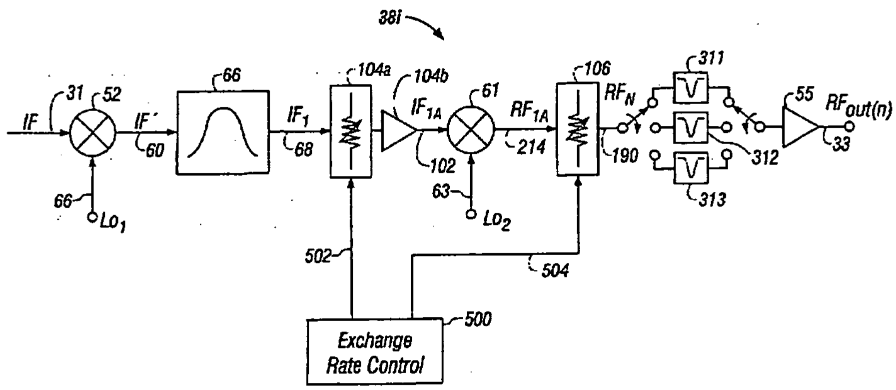

(57) Abrégé/Abstract:
An agile frequency converter and method employs an IF/RF exchange process to reduce the system noise generated by the frequency conversion process in generating a broadband composite signal. The converter employs a well-known two-stage frequency conversion process, but amplifies the intermediate output signal generated by the first conversion stage to boost the input to the second conversion stage, achieving a commensurate increase in the level of the output signal from the second conversion stage. This increased output level results in an increased signal-to-noise ratio between the RF channel carrier component and the system noise floor. The converted output signal is then attenuated by an amount substantially equal to the amount of amplification of the intermediate signal prior to the second stage of conversion. The result of this attenuation is an RF signal having frequency components with amplitudes approximately equal to that which they would have had had the intermediate signal not been amplified, and results in a noise floor which is reduced by that same amount. Thus, the increased signal-to-noise ratio is maintained. The converter also employs two tunable notch filters in series for purposes of filtering two second-order distortion components that find their way back into the range of channel frequencies of the broadband signal. These tunable notch filters are employed because the IF/RF exchange process actually decreases the signal-to-distortion ratio for one of these components. For those RF channel frequencies that fall in the middle of the channel frequency range of the broadband signal, no IF/RF exchange is employed because one of the distortion components cannot be filtered because it is too close in proximity to the RF signal components. In this case, the second stage of the frequency conversion process is operated to produce an optimal signal-to-distortion ratio in the output of the converted signal, including no amplification of the intermediate signal. The tunable notch filters employ two varactors in a back to back push-pull configuration to eliminate first order distortion in the transfer function of the filters.

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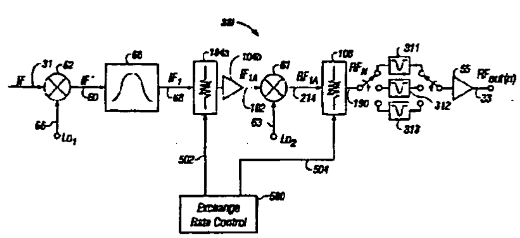
(54) Title: AGILE FREQUENCY CONVERTER FOR MULTI-CHANNEL SYSTEMS WITH IF/RF EXCHANGE AND LOW LOSS SPURIOUS NOISE REJECTION



(57) Abstract: An agile frequency converter and method employs an IF/RF exchange process to reduce the system noise generated by the frequency conversion process in generating a broadband composite signal. The converter employs a well-known two-stage frequency conversion process, but amplifies the intermediate output signal generated by the first conversion stage to boost the input to the second conversion stage, achieving a commensurate increase in the level of the output signal from the second conversion stage. This increased output level results in an increased signal-to-noise ratio between the RF channel carrier component and the system noise floor. The converted output signal is then attenuated by an amount substantially equal to the amount of amplification of the intermediate signal prior to the second stage of conversion. The result of this attenuation is an RF signal having frequency components with amplitudes approximately equal to that which they would have had had the intermediate signal not been amplified, and results in a noise floor which is reduced by that same amount. Thus, the increased signal-to-noise ratio is maintained. The converter also employs two tunable notch filters in series for purposes of filtering two second-order distortion components that find their way back into the range of channel frequencies of the broadband signal. These tunable notch filters are employed because the IF/RF exchange process actually decreases the signal-to-distortion ratio for one of these components. For those RF channel frequencies that fall in the middle of the channel frequency range of the broadband signal, no IF/RF exchange is employed because one of the distortion components cannot be filtered because it is too close in proximity to the RF signal components. In this case, the second stage of the frequency conversion process is operated to produce an optimal signal-to-distortion ratio in the output of the converted signal, including no amplification of the intermediate signal. The tunable notch filters employ two varactors in a back to back push-pull configuration to eliminate first order distortion in the transfer function of the filters.

WO 01/89079 A2

AGILE FREQUENCY CONVERTER FOR MULTI-CHANNEL SYSTEMS WITH IF/RF EXCHANGE AND LOW LOSS SPURIOUS NOISE REJECTION

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to the up-conversion of the component frequencies of each of a set of baseband signals modulated using the same intermediate frequency (IF), to a unique set of radio frequency (RF) signal components so that the baseband signals can be combined and distributed as a single composite broadband signal, and more particularly to an improved agile frequency conversion method and apparatus that attenuates the cumulative broadband system noise and spurious noise signals of the composite signal, to which each of the up converted RF signals contributes, to a level below the carrier-to-noise (C/N) and Garner-to distortion (CID) performance levels specified for the multi-channel system.

2. Background of the Related Art

In typical broadband multi-channel systems such as those used for cable television transmission, each of a set of baseband signals (5, Fig. 3) is modulated using the same standard IF carrier frequency. In the case of video signals, the baseband signal (occupying a frequency range of DC to 4.2 MHz) is modulated with an IF sub-carrier of 45.75 MHz using amplitude modulation (AM), and baseband audio signals (occupying a frequency range of 20 Hz to 20 KHz) are modulated with an IF sub-carrier of 41.25 MHz using frequency modulation (FM). These two modulated components are added together to create a composite IF signal. The composite IF signals representing the set of baseband signals are then typically combined at the head-end of the system for distribution to subscribers in the form of a single composite broadband signal. The composite broadband signal is created by up-converting the IF composite signal frequency components for each of the source signals to one of a unique set of composite RF (radio frequency) signals, each assigned to a unique RF channel.

The RF channel signals are then summed together to form the composite broadband signal, and the source signals are delivered to the subscriber's equipment

together over these channels. The subscribers then tune the receiving equipment to a specific RF channel carrier frequency to extract the desired source signal components from the composite signal. The composite broadband signal contains not only the source signals, but cumulative distortion components associated with each of the RF composite signals (artifacts of the up-conversion process) as well as cumulative broadband noise to which each of the RF signals also contributes. Reducing the effects of these noise and distortion components to reach acceptable levels of system performance poses one of the more significant and challenging problems faced by designers of such broadband multichannel systems.

Fig. 1 provides a simple conceptual illustration of the typical up-conversion process that occurs in multichannel systems such as cable television. Source baseband television signals (5, Fig. 3) are modulated to form the composite IF signals 10. Each of the composite IF signals 10, are then up-converted to one of a unique set of composite RF channel frequency ranges 12 occupying a radio frequency (RF) bandwidth 14. Because the baseband audio and video signals are actually comprised of a range of frequency components, so also are the composite IF and RF signals. It is simpler, however, to refer to each composite signal by a primary carrier frequency component even though the entire range of frequencies in the signal is converted. The RF channels 12 of frequency bandwidth 14 are typically 6 MHz wide for a multichannel television system, to accommodate the range of frequency components of the composite signals. The RF frequency bandwidth 14 for cable television systems typically ranges between approximately 50 MHz and approximately 870 MHz (i.e. 120 channels at 6 MHz per channel).

Fig. 2 illustrates one of the *n* single RF channels 12 of RF frequency bandwidth 14, along with spurious noise components 20 and system noise 22 generated during the up-conversion process. Although for a single channel these components do not pose a problem, when 60 to 120 channels are summed together to create the composite broadband output signal, the spurious noise signals are superimposed on one another and therefore can interfere with other composite RF signals occupying other RF channels in the RF frequency bandwidth 14. Moreover, the system noise 22 for each of the channels is summed together so that the noise floor 24 rises to unacceptable levels.

Fig. 3 is a conceptual representation of the summing process that occurs to create a composite broadband signal at the head end of a multichannel system such as cable television. Each channel processor 30 generates a frequency converted composite RF signal 39 that is combined with the other composite RF signals 39 using conceptual summing element 32 prior to distribution of the composite broadband signal 34. The multichannel system is typically designed such that each of the channel signals 39 comprising the broadband signal is normalized to the same power level. Thus, the noise components that are produced by the up-conversion of each of the composite IF signals to a composite RF signal will have the same power, and therefore have the same relative power to the components of both the composite RF channel signals upon which they are superimposed as well as to the RF channel signal components with which the noise signals were generated. Put another way, a spurious noise signal that is minus 60 dB from the power level of its own channel carrier signal component will therefore be 60 dB down from the power of the carrier signal component of the channel into which the noise signal falls. As a result, to ensure that the overall broadband system meets the combined noise performance specification, a designer can perform this optimization with respect to the conversion process for a single channel. In today's television cable systems, it is expected that each channel should have no less than a 65 dB attenuation of both spurious noise signals and cumulative broadband noise relative to the signal power of the carrier signal components of the various channels. These two specifications are commonly referred to as carrier to distortion (C/D) and carrier to noise (C/N) respectively.

One seemingly obvious approach to solving the problem of eliminating, or at least attenuating, spurious noise signals in the broadband signal is simply to filter each RF output signal (5, Fig. 3) corresponding to an assigned channel through a band-pass filter substantially tuned to the RF carrier frequency of the assigned channel to attenuate the out-of-band signals 20 and 22. The problem with this approach is that an up-converter would have to be manufactured with a different band-pass filter having a center frequency determined by the RF channel to which it is assigned. This requires that the multichannel system be statically designed, whereas today's multichannel systems applications demand agility in design such that each channel processor 30 is capable of assignment to any channel in the RF channel frequency range 14. This solution would

require equipment manufacturers to manufacture, test and stock different channel processors 30 for each channel frequency range, increasing manufacturing costs and requiring purchasers to maintain an inventory of replacement parts for each of the channel processors 30. Because a cable television system can provide between 60 and 120 channels, this solution becomes impractical and cost prohibitive. Nor can tunable bandpass filters be used to render this solution agile, because tunable bandpass filters include non-linear elements that would themselves introduce distortion into the broadband signal, making achievement of the 65 dB C/N and C/D specifications virtually impossible.

Fig. 4 is a conceptual illustration of a channel processor 30. Those of skill in the art will recognize that channel processors 30 may contain additional elements, but the elements pertinent to this discussion include up-converter 38 and modulator 36. Modulator 36 performs the modulation of a baseband source or information signal 5 (including video 35 and audio 37 signals for cable television) to create the composite IF carrier signal component 31 IF signal component 31 is then provided to up-converter 38, which takes the composite IF signal component 31 and converts it to composite RF signal carrier component 33 at a frequency falling within the channel frequency range 14 corresponding to the channel 12.

Fig. 5a provides a simple conceptual representation of a single channel up-converter 38. Composite IF signal 31 is input to a mixer 52 and combined with the local oscillator (L_0) signal 56 to produce composite RF signal 33. The composite RF signal 33 has several other components, including two sideband components 42 and 51 and other distortion and leakage components 44 and 58. Composite RF signal 33 is passed through bandpass filter 54 having transfer function 48 to produce a single-sideband RF output signal 42. Fig. 5b provides an illustration of the signals produced by the up-conversion process. The result of the mixing process produces the two sideband components 42 and 51. Sideband component 42 has a frequency that is equal to L_0 - IF, and sideband component 51 has a frequency equal to L_0 + IF. Due to leakage through the imperfect mixer 52, a component 44 is produced at the carrier frequency of L_0 as well as a component 58 at the primary carrier frequency of IF. Bandpass filter 54 as shown in Fig. 5a is intended to produce a transfer function 48 that permits only signal component 42 to

be output to the system. By this process, the carrier signal component of IF is converted up to an RF carrier signal component 42 equal to L_0 IF.

To isolate the desired the sideband carrier component 42, while meeting the performance specifications required of a multichannel system such as cable television, signal components 58, 44 and 51 must be attenuated to a level that is 65 dB below the signal level of carrier component 42. The signal level of carrier component 42 is already 7 dB below the signal level of IF 31. This is because the mixer creates a conversion loss of about 7 dB. Moreover, mixer 52 can require a range of power levels for L_0 56 on the order of 7 dBm to 21 dBm. Although it might be desirable to overcome the conversion loss of the mixer by increasing the power of IF 31, this will cause the levels of distortion components to increase on RF 33. Thus the upper limit to the input level of IF 31 is approximately -10 dBm and the output power of RF 33 will be -17dBm. If the mixer 52 requires the signal L_0 56 to be 20 dBm and the L_0 rejection is approximately 25 dB, then L_0 the leakage component 44 will be approximately 12 dBm hotter than the sideband signal component L_0 42. Therefore, to reach the -65 dB specification, the filter must actually attenuate the leakage component 51 by at least 77 dB. Such a response is difficult to reach with a fixed bandpass filter, let alone one which is tunable.

In an attempt to meet this difficult performance specification while maintaining an agile system, a dual or two-stage frequency conversion has been used. Fig. 6a illustrates the concept of a dual or two-stage frequency converter. For the first conversion stage, composite signal IF 31 is input to mixer 52 along with a local oscillator signal L_0 66 and a resulting composite signal IF' 60 is produced and input to a fixed bandpass filter 66.

Bandpass filter 66 then produces composite signal IF_1 68. For the second conversion stage, IF_1 68 is input to a second mixer 61 and mixed with a second local oscillator signal L_{02} 63 to produced a desired RF signal 65 that falls within the multichannel RF frequency bandwidth 14 in accordance with the channel to which it is assigned. The signal RF 65 is then input to RF attenuator 67, which produces an output RF_N 57 that is normalized to a constant power level relative to each of the RF outputs of the other frequency.

Fig. 6b provides a conceptual illustration of the results of this dual conversion process. The affect of the first conversion stage as accomplished by mixer 52 takes one of the composite IF signals 70 and up-converts it to produce output IF' 60, which includes two sideband components 74 and 71, with the carrier frequency of sideband component 71 equal to approximately 1 GHz; sideband component 71 is equal to L_{01} + IF. It should be noted that the leakage component 73 corresponding to local oscillator signal L_{01}, 66 now falls outside of the multichannel frequency bandwidth 14. Sideband component 74, as well as leakage component 73 are then eliminated by fixed bandpass filter 66 such that composite signal IF_1 68 contains only upper sideband component 71. The second conversion stage as performed by mixer 61 then places sideband component 71 into the multichannel frequency bandwidth 14 by mixing IF_1 68 with local oscillator signal L_{02} 63 to produce a lower sideband component 76 at a carrier frequency equal to L_{02} -IF_1. It should also be noted that upper sideband component (having a frequency equal to L_{02} + IF_1) generated by this second mixing step, as well as the leakage component 75 associated with local oscillator signal L_{02}, both fall outside of the multichannel frequency bandwidth 14 as well.

Those with skill in the art will recognize that this prior art two-stage conversion technique eliminates the need to remove leakage and unwanted sideband components from the signal RF 65 because all of the unwanted signals fall outside of the RF channel frequency range 14. Thus, each channel processor can be assigned to any one of the RF frequency channels contained in bandwidth 14 simply by adjusting the value of local oscillator frequency L_{02} 63 between the frequency values of about 1070 MHz and approximately 1880 MHz.

Generating local oscillator L_{01}, and local oscillator L_{02} leakage components, as well as unwanted sideband components with frequencies that fall outside of the multichannel RF frequency spectrum 14 using the two-stage conversion method of the prior art does not, however, solve all of the problems associated with spurious and broadband noise components. Two additional second-order distortion components of concern still exist and still find their way into the RF channel frequency spectrum 14. One such component is the second harmonic of the composite RF signal 81 as illustrated in Figs. 7a and 7b. The carrier frequency of this second harmonic is equal to 2RF. A

second distortion component 82 of concern has a carrier frequency equal to IF_1 - RF. As can been seen from Figs. 7a and 7b, as the frequency of RF 80 increases, the second harmonic signal increases in frequency at the rate of 2RF and the second distortion component 82 decreases in frequency and moves right to left on the frequency graph of Figs. 7a and 7b. The second harmonic distortion component 81 does not present as much of a problem because it is not difficult to filter; it is always at twice the frequency of the desired RF component 80. As can be seen from Fig. 7b, however, the second distortion component 82 as it moves from right to left with decreasing frequency, can at some point fall directly within the very channel frequency band to which the converted composite RF signal is assigned. When this occurs, or even when the frequency of this distortion component is close in proximity to the components of the converted RF signal, it is clear that the bandpass filter solution will not work because it is too close to the converted signal carrier RF 80 to be attenuated by filter to meeting the -65dB noise specifications.

One well-known prior art approach to dealing with the second order distortion component 82 problem is to simply design all of the channel processors 30 such that the level of the distortion component 82 will always be guaranteed to be 65 dB down from the power level of the converted RF signal carrier 80, so that no attenuation by filtering is required. This has been accomplished through the design of mixer 61 and the choice of input levels for signals IF_1 and L_{O2}. Put another way, mixer 61 of Fig. 6a must be operated in a manner and under such conditions that the distortion component 82 of Figs. 7a and 7b will always be a minimum of 65 dB down from the power level of the channel carrier signal component of RF 80.

One of the constraints on operation of mixer 61 will be that of the maximum input to level of IF_1 68 into mixer 61. For every 1 dBm increase in signal power of IF_1 68, the distortion component 82 (the frequency of which is determined by IF_1 - RF) will increase by 2 dB. Thus, for every 1 dB of increase in RF_1, there will be a loss of 1 dBc/dB in the C/N ratio. As a result, an upper limit is imposed on the maximum input level that is possible for IF_1 68.

The prior art two-stage frequency converter of Fig. 6a must meet the cumulative broadband or system noise performance requirement of -65 dB as well. The level or

noise floor system noise is independent of the input levels of mixer 61. To meet the specification, the prior art employs a bank 69 of six switched bandpass filters 53 that essentially divides the RF channel bandwidth 14 into six frequency ranges. The channel processor 30 selects the appropriate one of the six switched filters 53 designed to handle the frequency range in which the channel processor's assigned channel frequency resides. In this way each of the channel processors 30 has a final bandpass filter 53 through which the normalized RF_N signal 57 is filtered to attenuate broadband noise occupying that frequency range to a level such that when all of the channels of the system are combined into composite signal 34 of Fig. 3, the cumulative broadband noise falls below the performance specification of -65 dB.

This solution is expensive because each of the channel processors 30 must have the six switched bandpass filters and it must also have the mechanism by which to select and switch in the appropriate filter. Moreover, as the performance level demanded by multichannel systems continues to increase, it will be more difficult for these switched bandpass filters to provide sufficient attenuation by which to meet the composite noise performance specifications. Finally, there must be sufficient amplification of the RF_N output signal 57 to drive the switch bank 69 for the bandpass filters 53, and the component required to drive such a switched bank consumes a considerable amount of power.

Thus, there is room in the art for a method and apparatus for converting modulated baseband signals to RF channel signals that will reduce the broadband noise of the composite broadband signal 34 without the need for cumbersome and costly switched filters, while further reducing levels of undesirable distortion components in the composite signal, all while maintaining system agility.

SUMMARY OF THE INVENTION

It is one objective of the method and apparatus of the present invention to provide improved carrier-to-noise (C/N) and carrier-to-distortion (C/D) performance in multichannel broadband systems, by alternating the system noise and distortion components generated during the frequency conversion process typically performed in creating a broadband multichannel signal.

It is further an objective of the present invention to eliminate the need for switched band-pass filters, typically employed in the prior art frequency conversion to attenuate the system noise generated during the conversion process to ensure that the broadband output signal meets the carrier-to-noise (C/N) specification of the multi-channel system.

In accordance with the present invention, the foregoing and other objectives are achieved by an improved frequency up-conversion method and apparatus in which an IF-RF exchange is employed. The IF/RF exchange is employed in a well-known two-stage frequency conversion process whereby the IF output component of the first conversion stage of the conversion process is amplified prior to its input into the second conversion stage of the converter. The amplification of the IF signal component results in an increase in the level of the converted RF output signal, but does not result in an increase in the system noise generated during the second stage conversion. Thus, the difference between the carrier signal and the noise floor has been increased by the amount of the amplification. The amplification does, however, produce an increase in the levels of spurious noise distortion components. The converted RF output including the desired RF carrier components, the system noise component and any distortion components are all then attenuated to a level approximately equal to that which they would have occupied had the IF signal not been amplified to begin with. As a further result of the attenuation, the system noise floor is reduced by an amount substantially equal to the amplification of the intermediate signal prior to the second stage conversion. The system noise contributed to the composite broadband signal by each of the signals converted using the IF/RF exchange has thereby been substantially reduced.

The frequency converter and method of the present invention also attenuates two second-order distortion components from the RF converted output of each channel to reduce spurious noise in the composite broadband signal. To accomplish this, the present invention employs two tunable notch filters that can be tuned to filter these two distortion components. Because these components are a function of the RF channel frequency component of the output signal, they will reside at different frequencies for each given channel frequency. Thus, the notch filters are tunable so that they may be tuned to the frequency of the distortion components as the channel frequency varies. The notch filters

utilize a pair of varactors in a to push-pull configuration that is coupled in parallel with an inductance. The voltage across the varactors can be adjusted to vary the capacitance that is in parallel with the inductance to tune the filter to the appropriate frequency of the distortion components. The push-pull configuration of the varactors tends to offset or eliminate first order non-linearity in the transfer function of the notch filters.

There is a given range of channel frequencies for which one of the distortion components becomes too proximate to the desired RF channel frequency carrier component to be successfully filtered by either of the tunable notch filters. Moreover, one of the distortion components, which is equal to the frequency of IF minus the converted RF output frequency, actually increases in level with respect to the level of the desired output RF channel frequency component which in turn increases the spurious noise contributed to the composite broadband signal. Therefore, the present invention does not perform the IF/RF exchange for those channel frequencies for which the distortion component becomes too proximate to the desired RF channel frequency component. In this case, the second stage of the converter is configured to operate to produce the best case carrier-to-distortion (C/D) performance possible to ensure that the conversion process generates distortion components that will still meet the specification.

Because the frequency converter and method of the present invention eliminates the switched band-pass filters typically used with prior art frequency converters, a significant number of components are eliminated, including an amplifier which is required to overcome the loss that the converted output signal experiences through the switched filters. By eliminating these components, cost and complexity, as well as power dissipation are significantly reduced for each of the channel processors of the system.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the method and apparatus of the present invention may be had by reference to the following detailed description when taken in conjunction with the accompanying drawings wherein:

Figure 1 is a conceptual representation of a modulated information signal which is to be up-converted to one of *n* RF channels.

Figure 2 is a conceptual representation of an up-converted information signal to one of n RF channel, along with system noise and spurious noise components resulting from the conversion process.

Figure 3 is a conceptual representation of a system for producing a composite broadband multichannel signal from n information signals.

Figure 4 is a conceptual representation of one of the channel processor of Fig. 3 for performing frequency conversion of an information signal to an RF channel. Figure 5a is a conceptual representation of a single-stage frequency converter of the prior art.

Figure 5b is a conceptual representation of a converted output signal and its noise components generated by the converter of Fig. 5a.

Figure 6a is a conceptual representation of a prior art two-stage frequency converter.

Figure 6b is a conceptual representation of a converted intermediate and RF output signals resulting from the two-stage converter of Fig. 6a.

Figure 7a is a conceptual representation of second-order distortion components that result from the conversion performed by the frequency converter of Fig. 6a.

Figure 7b is a conceptual representation of the second order distortion components wherein one of the distortion components becomes too close in proximity to the converted RF channel component to be filtered without affecting the RF component.

Figure 8a is a conceptual representation of the desired RF signal component and the unwanted second-order distortion components resulting from the frequency converter of Fig. 6a where the desired channel frequency is at the low end of the channel frequency range.

Figure 8b is a conceptual representation of the relationship between the desired RF signal component and unwanted second-order distortion components of the output signal created by the converter of Fig. 6a when the desired channel frequency is in the middle of the 15 channel frequency range.

Figure 8c is a conceptual representation of the desired RF signal component and the unwanted second-order distortion components of the output signal generated by the frequency converter of Fig. 6a, where the channel frequency is at the high-end of the channel frequency range.

Figure 9 is a conceptual representation of the two-stage frequency converter of the present invention employing an IF/RF exchange.

Figure 10a is a conceptual representation of the desired RF signal component and the unwanted second-order distortion components generated by the frequency converter of the present invention, where the channel frequency is at the low-end of the channel frequency range.

Figure 10b is a conceptual representation of the amplification of the desired RF signal component and the system noise component of the output generated by the frequency converter of the present invention when using the IF/RF exchange process of the present invention.

Figure 10c is a conceptual representation of the desired RF signal component and the system noise component of the output of the frequency converter of the present invention after the attenuation step of the IF/RF exchange process has been employed.

Figure 11a is a conceptual representation of the desired RF signal component, the unwanted second-order distortion components, and the system noise component of the output of the frequency converter of the present invention where the desired RF channel frequency is at the low-end of the channel frequency range.

Figure 11b is a conceptual representation of the desired RF signal component, the unwanted second-order distortion components, and the system noise component of the output of the frequency converter of the present invention, where the desired RF channel frequency is in the middle of the channel frequency range.

Figure 11c is a conceptual representation of the desired RF signal component, second-order distortion components and the system noise component of the output of the

frequency converter of the present invention, where the desired RF channel frequency is at the high-end of the channel frequency range.

Figure 12a is a conceptual representation of the two tunable notch filters of the present invention connected in series.

Figure 12b is a conceptual representation of the responses of the two varactors as connected in a push-pull configuration.

Figure 12c is a conceptual representation of the transfer function of the notch filter in relationship to the voltage across the varactors of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

As previously discussed, the prior art solution to reducing broadband noise and distortion components generated during frequency conversion of baseband signals to RF channels in a multichannel system requires: 1) a bank of switched bandpass filters to accomplish attenuation of the broadband noise contributed by each of the channels; and 2) that operation of the second mixer of the two-stage frequency converter of the prior art be constrained to guarantee that all distortion components for every channel in the RF channel frequency range is a minimum of 65 dB down from the level of the converted signal output components. The method and apparatus of the present invention eliminates the requirement for a switched bank of bandpass filters while achieving as good or better noise performance than that of the prior art two-stage converter as illustrated in Fig. 6a.

The method and apparatus of the present invention first discards the assumption made in the prior art solution that each channel conversion should be treated based on the worst case scenario: where the second-order distortion component 82 of Figs. 7a and 7b falls too close to the RF signal component to be attenuated by filtering. With reference to Fig. 8a, three different RF output scenarios are illustrated based upon the range of desired RF channel frequencies to be targeted by a channel processor during conversion. In Fig. 8a, the signal carrier component RF_1 90 falling within the assigned RF channel is at the lower end of the RF channel frequency spectrum 14. This places both second-order distortion components 92 and 94 inside of the multichannel RF channel frequency range

14, but sufficiently far enough from channel carrier component RF_1 90 that they could be filtered after generation of RF_1 90.

Fig. 8b illustrates a channel carrier signal component $RF_2$98 which corresponds to an RF channel with a frequency range that falls more in the middle of the multichannel RF channel frequency spectrum 14. While second-order distortion component 93 has all but moved out of the RF channel frequency spectrum 14, distortion component 91 has moved closer in proximity to channel carrier signal component 98 such that it would not be possible to attenuate distortion component 91 from the signal RF_2 98 using known filtering techniques without affecting the signal components of the RF output itself. This is the worst-case scenario for spurious noise attenuation. In Fig. 8c the RF channel frequencies to which the baseband signal components are to be converted based on channel assignment are now at the high-end of the RF channel frequency spectrum 14 and as such, the second harmonic component has moved outside the range of the graph in Fig. 8c and distortion component 95 has moved sufficiently to the other end of the RF channel frequency spectrum 14 that once again this distortion component can be attenuated by filtering the converted output signal including carrier signal component RF_3 97.

As previously discussed, the prior art solution is- to simply assume the worst case for all channel frequencies even though for only a subset of the channel frequencies will the second-order distortion components (having frequencies given by IF_1 - RF_N) be too close in proximity so that they can not be sufficiently attenuated by filtration (the worst-case scenario of Fig. 8b). The method and apparatus of the present invention, as illustrated in Fig. 9, handles this worst-case scenario as illustrated by Fig. 8b (and as in the prior art. The RF channel carrier frequencies for this scenario are all frequency converted with the input levels and the design of mixer 61 constrained to ensure that the specified relationship of -65 dB between the level of the RF signal components and the distortion component levels are maintained.

With respect to the scenarios depicted by Figs. 8a and 8c, however, the input power level of the composite signal IF_1 68 is first amplified by RF attenuator circuit 104 prior to the second conversion stage using mixer 61, thereby increasing the output power

level of the components of composite output signal RF_{1A} 214 commensurately. This amplification of IF_1 68 serves to raise the power level of the RF_{1A} output signal 214 relative to the system or broadband noise floor 24; the broadband or system noise 22 generated during the conversion process is unrelated to the IF_1 68 signal level. Once the second conversion stage is completed, RF attenuator 106 is used to attenuate the level of the entire composite RF_{1D} signal, including the broadband noise 22 and the second order distortion components. The result of this IF/RF exchange is illustrated in Figs. 10a-c.

In Fig. 10a, the prior art relationship between the level of carrier component RF 90 of the output signal and the system noise floor 24 is illustrated by bracket 112. In Fig. 10b, RF carrier component RF_{1A}214 is generated with an increased level 114 by increasing the input signal IF using attenuator 104 and then performing the second conversion stage using mixer 61. Note that the noise floor 24 of system noise 22 resulting from the conversion remains the same as for the conversion performed without the amplification of IF_1 68. Signal RF_{1A}214 is then attenuated using a second RF attenuator 106, which serves to attenuate the composite RF signal including the RF channel carrier component back to a normalized level approximately equal to that which it would have been had composite signal IF_1 68 not been amplified. This attenuation also serves to attenuate system noise 22 (as well as all distortion components) such that the noise floor 24 now resides at a level 118 that is less than previous level 24 by an amount that is approximately equal to difference 114. Thus, the result of the conversion of the present invention using the IF/RF exchange process is to decrease the amount of system noise contributed to the broadband signal by each such converted signal by an amount substantially equal to the gain produced by the amplification of IF_1 68 prior to the conversion. This reduction in noise contribution is achieved by the present invention with the addition of only an attenuator to the prior art two-stage converter, while eliminating the need for the switched bandpass filters 53 used in the prior art.

With respect to the distortion components, as previously discussed, increasing the input level to the mixer by 1dB leads to a 1 dB increase in the RF output, but there will be a loss of 1 dBc/dB in the C/N ratio with respect to the distortion component 82 of Figs. 7a and 7b. Moreover, because mixer 61 is not being constrained to produce distribution components at -65 dB or greater, even distortion component 81 can exceed

the specification. Thus, for the two scenarios for which the IF/RF exchange is employed (Figs. 11a and 11c) by the method of the present invention, the level of these distortion components actually is increased with respect to the components of the converted signal after attenuation and therefore must be attenuated.

With respect to Figs. 11a-c, because the channel frequency scenarios of Figs. 11a and 11c now use the IF/RF exchange of the present invention, the distortion components (i.e. IF_{1A} - RF_{1A} 194, $2RF_{1A}$ 192 and IF_{3A} - RF_{3A} 195, $2RF_{3A}$ 197) are amplified and then attenuated as well. Because the IF_{1A} - RF_{1A} component increases at 2x the level of increase of RF_{1A} as a function of input level IF_{1A}, this distortion component will end up increasing with the respect to the final value of RF_{1D}. This increase is depicted in Figs. 11a and 11c.

Thus, this component must be filtered for those channel frequencies using the IF/RF exchange. Also as previously mentioned, there is no guarantee that the component $2RF_{1A}$ meets the specification either, so it should be filtered as well.

Fig. 9 illustrates that these components are filtered by the method and apparatus of the present invention using two tunable notch filters 108 and 110. These filters produce the characteristic transfer functions 120 and 122 as illustrated in Figs. 11a-c. As shown, for the first and third scenarios (Figs. 11a and 11c respectively), the notches are tuned to the distortion component frequencies to selectively remove both of the distortion components.

As the components cross over, the filters can switch responsibility for the two distortion components. Also note that the noise floor 24 for these scenarios has been reduced by the IF/RF exchange as previously discussed.

For the worst case scenario, Fig. 11b shows that notch filter 106 is parked such that its transfer function 120 lies outside of the channel frequency range of interest when the distortion component is too close to the generated RF channel carrier frequency. Also note that the noise floor 24 for this scenario remains as it was without IF/RF exchange. It will be clear to those of skill in the art that the reduction in system noise contributed by the converted signals for channel frequencies of the scenarios of Figs. 11a and 11c must

be reduced to a level that makes up for the fact that no such reduction occurs at all for the worst case scenario of Fig. 11b. Because for this scenario the mixer 61 is operated to with constraints sufficient to ensure that distortion components are at a level that is -65dB or greater from the RF carrier levels, no filtration of the components is necessary to meet the C/D specification.

An embodiment of the tunable notch filters 106, 108 is now described with respect to Fig. 12a. Each notch filter 106, 108 is made up of a pair of varactors that are connected in a push/pull configuration, and in parallel with an inductance L_1 230 and L_2 238 respectively. The varactors act as variable capacitors with their capacitance a function of the voltage across them. Because of the push/pull configuration, the first-order non-linear characteristics 250, 252 of the two varactors 224, 226 and 232, 234 respectively tend to cancel each other out as shown in Fig. 12b. By varying the voltage V_{t1} 220 and V_{t2} 236 respectively, the varactor transfer functions can be tuned with the inductors L_1 230, L_2 238 respectively such that the voltage across the diodes is a at a minimum at the RF channel carrier frequency, and at a maximum at the fundamental frequencies of the distortion component. This voltage characteristic 260 is illustrated in Fig. 12c for the second harmonic of the RF channel frequency component, along with the resulting transfer function 268 of the notch filter.

These filters are simple and reasonably linear despite their tunable nature. The IF/RF exchange in combination with the notch filters serves the purpose of eliminating the distortion components to make the IF/RF exchange feasible for two of the three output scenarios. This enables the multichannel system of Fig. 3 to generate a composite broadband signal that meets both the C/N and C/D specifications for the system without need for the complicated switched filters of the prior art. The prior art switched filter scheme is complex and produces a 3 dB loss to the output that must be compensated by use of an RF amplifier that dissipates considerable power.

Those of skill in the art will recognize that the embodiments of the invention are for purposes of illustration only, and the claims should not be based on such embodiments. For example, the present invention has been illustrated within the context of analog cable television systems, but can be applied to any multichannel system,

including digital television, that requires the up-conversion of signals for purposes of combining them to form a multichannel broadband signal.

WHAT IS CLAIMED IS:

1. A method of generating a broad based signal comprising a plurality of channels, each of the channels comprising a unique subset of a contiguous range of channel frequencies, said method comprising the steps of:

assigning each of a plurality of information signals to a different one of the channels, each of the information signals comprising at least one frequency component having a first frequency;

converting the at least one frequency component of each of the information signals from the first frequency to a second frequency, wherein the second frequency is contained within the subset of the channel frequencies corresponding to the channel to which each information signal is assigned, said step of converting further comprising:

mixing the information with signals with a first local signal having a third frequency to generate an intermediate output, the intermediate output having a frequency component equal to an intermediate frequency;

amplifying the level of the intermediate output;

mixing the amplified intermediate output with a second local signal having a fourth frequency to generate a converted output having a frequency component equal to the second frequency; and

alternating the converted output; and summing the converted outputs for each of the plurality of modulated signals.

2. The method of Claim 1 wherein the attenuation of the converted signal is sufficient to reverse the amplification of the intermediate output and to normalize the converted signals to substantially the same output level.

3. The method of Claim 2 wherein the step of converting further comprises the step of filtering a component of the converted output having a frequency equal to two times the second frequency.

4. The method of Claim 2 wherein the step filtering of converting further comprises the step of a component of the converted output having a frequency equal to the intermediate frequency minus the second frequency.

5. The method of Claim 1 wherein the steps of amplifying and attenuating are skipped for those information signals for which a distortion component having a frequency equal to the intermediate frequency minus the second frequency cannot be filtered without affecting the converted signal.

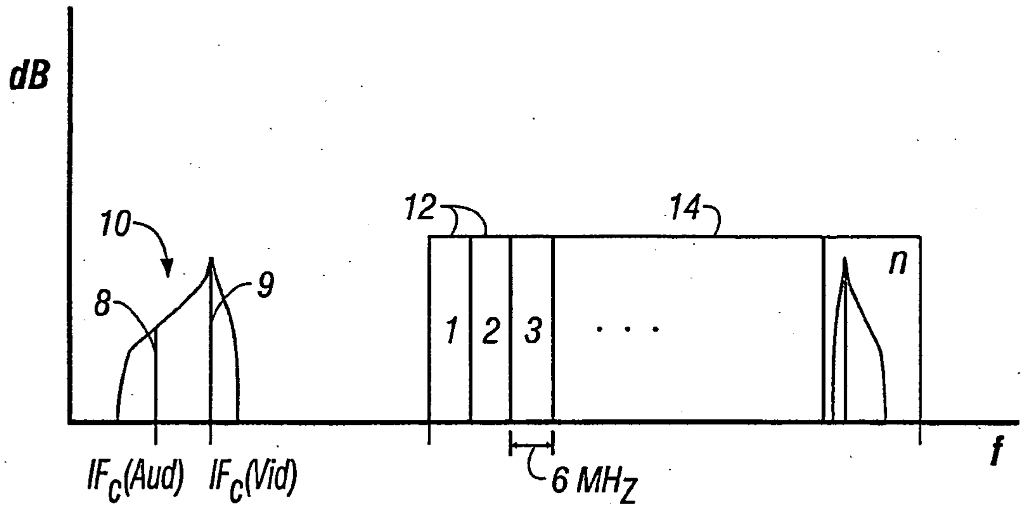


FIG. 1
(Prior Art)

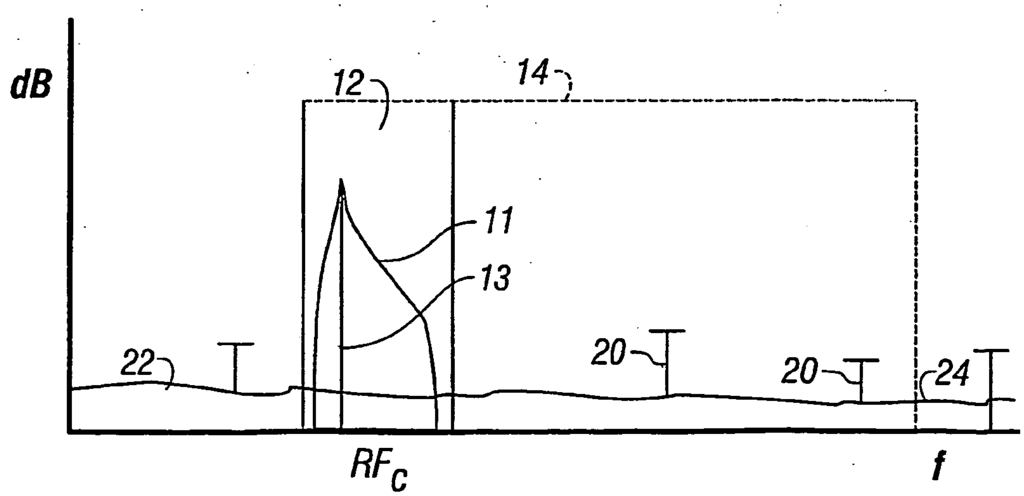


FIG. 2
(Prior Art)

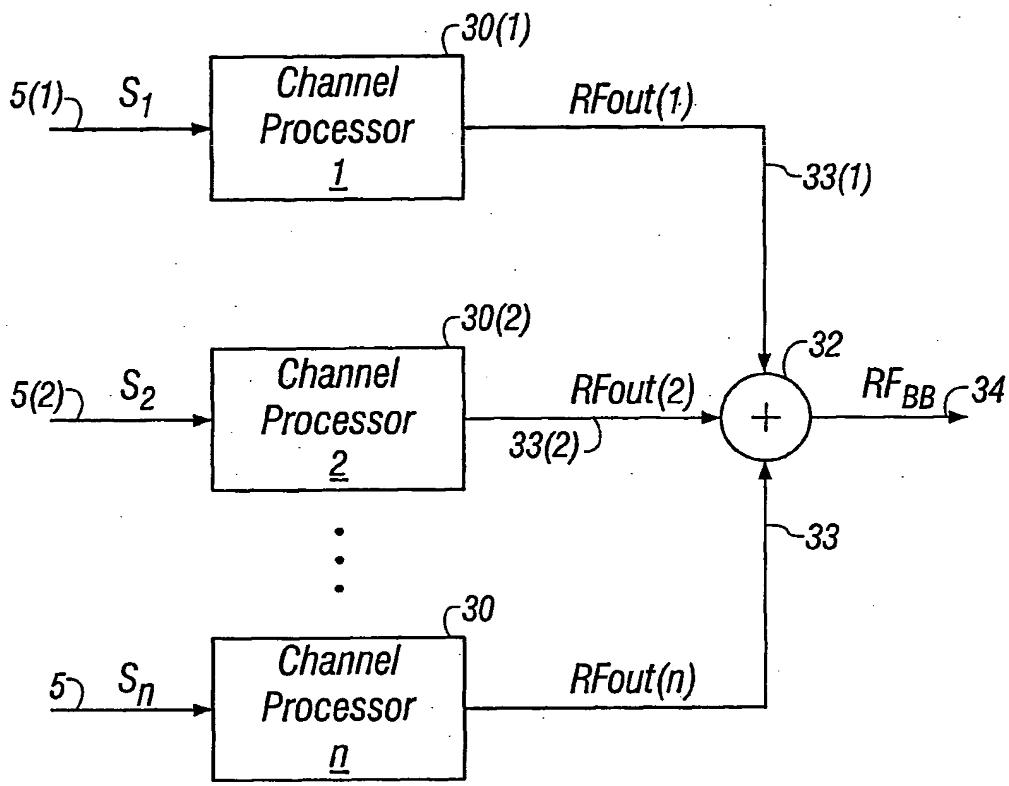


FIG. 3
(Prior Art)

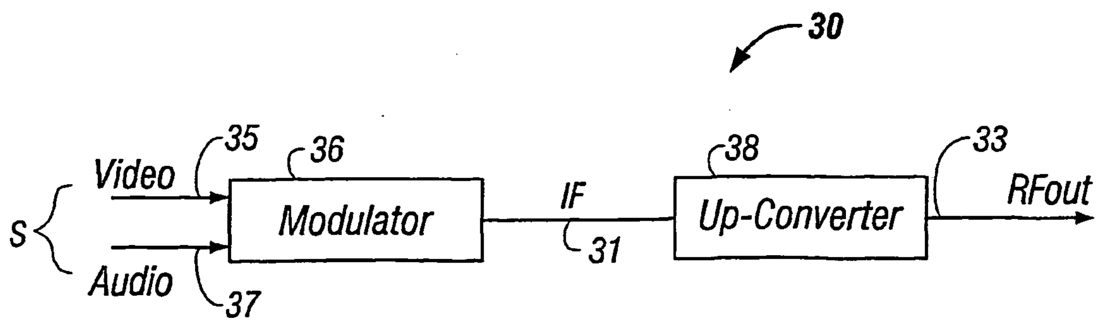


FIG. 4
(Prior Art)

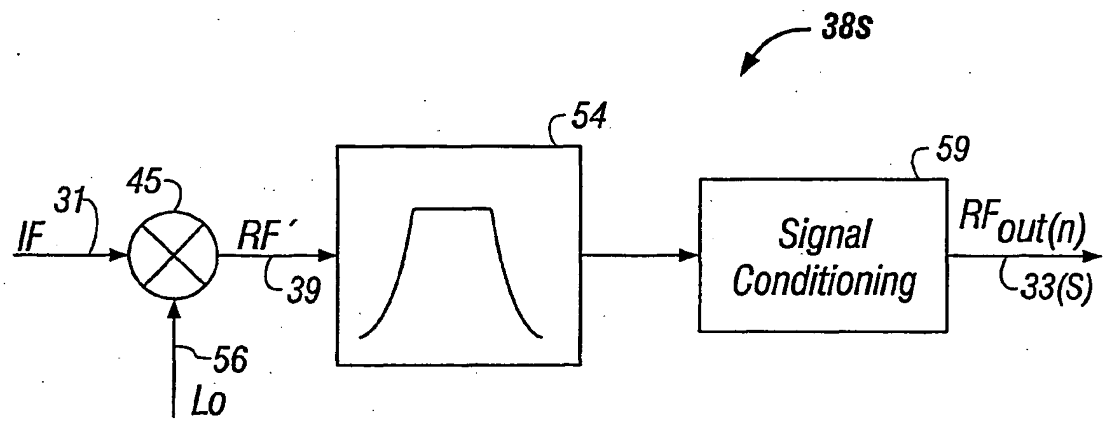


FIG. 5A
(Prior Art)

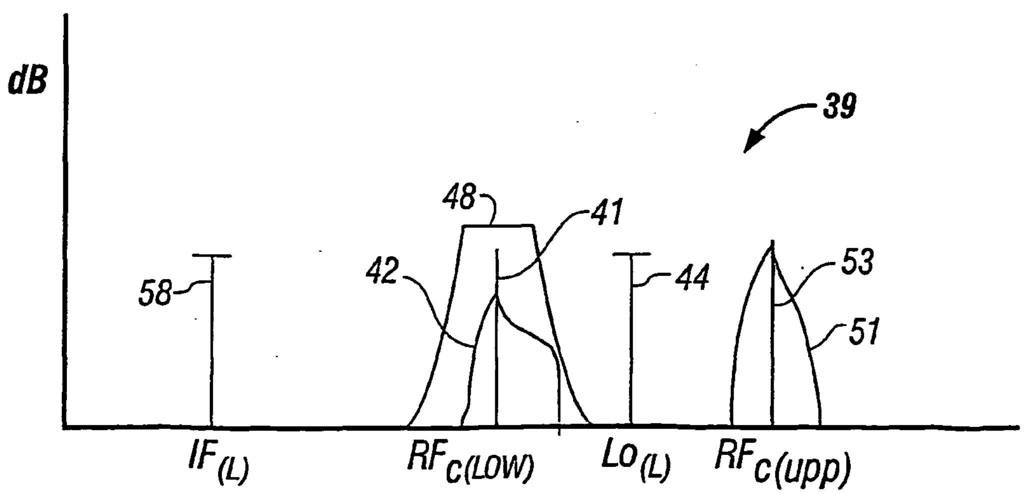


FIG. 5B
(Prior Art)

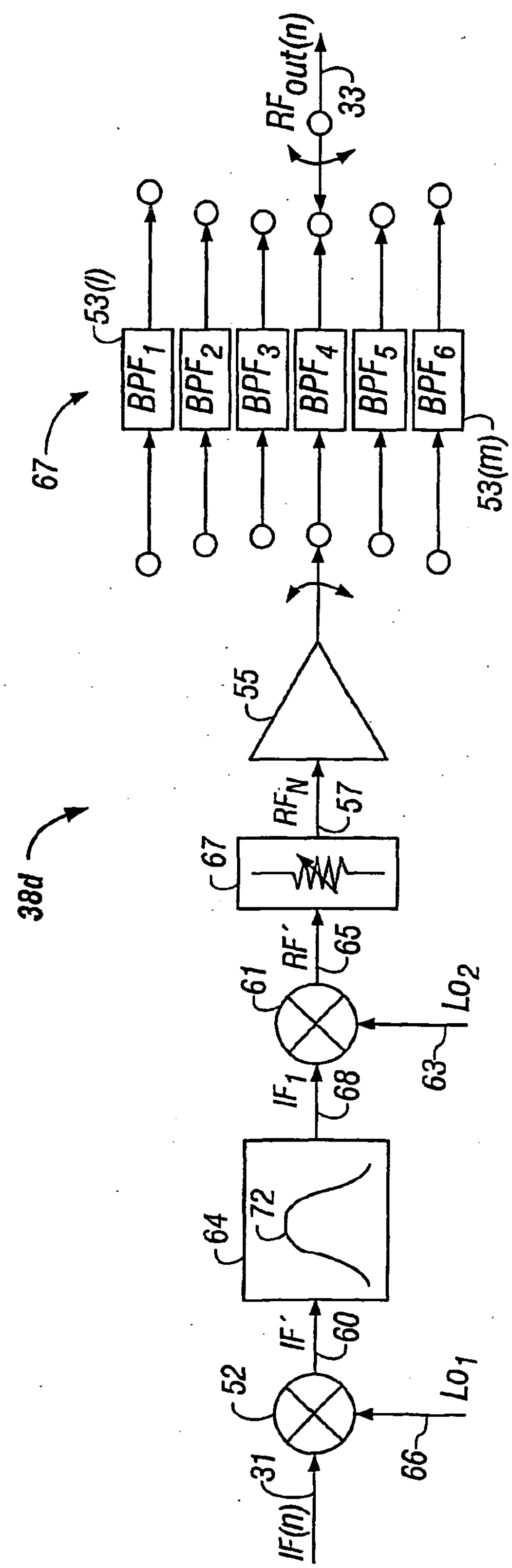


FIG. 6A
(Prior Art)

5/13

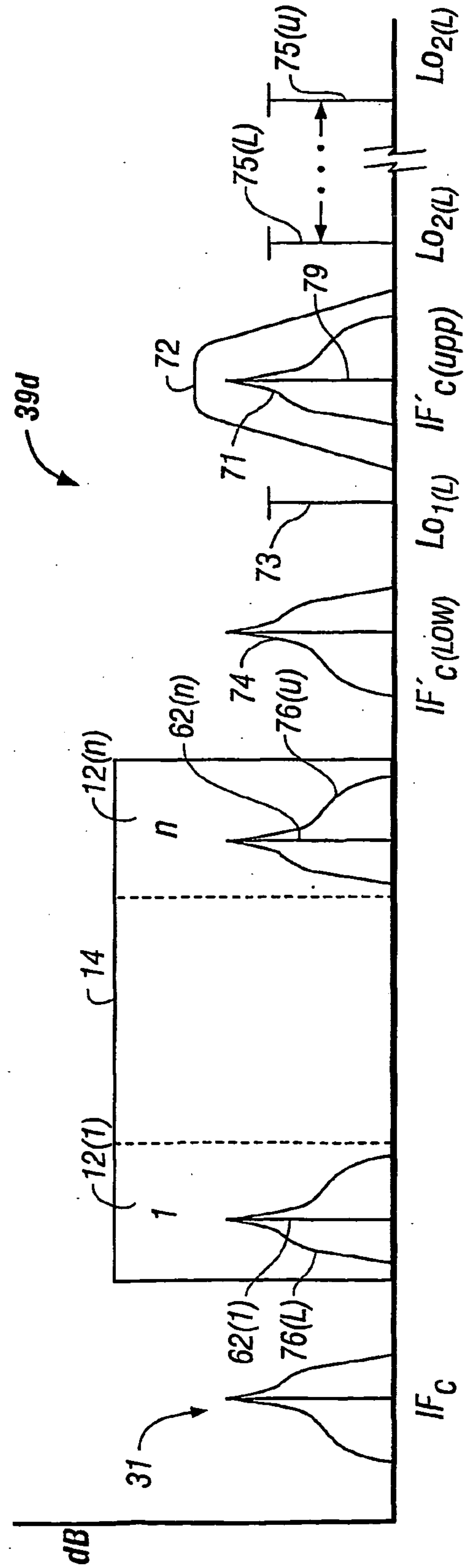


FIG. 6B
(Prior Art)

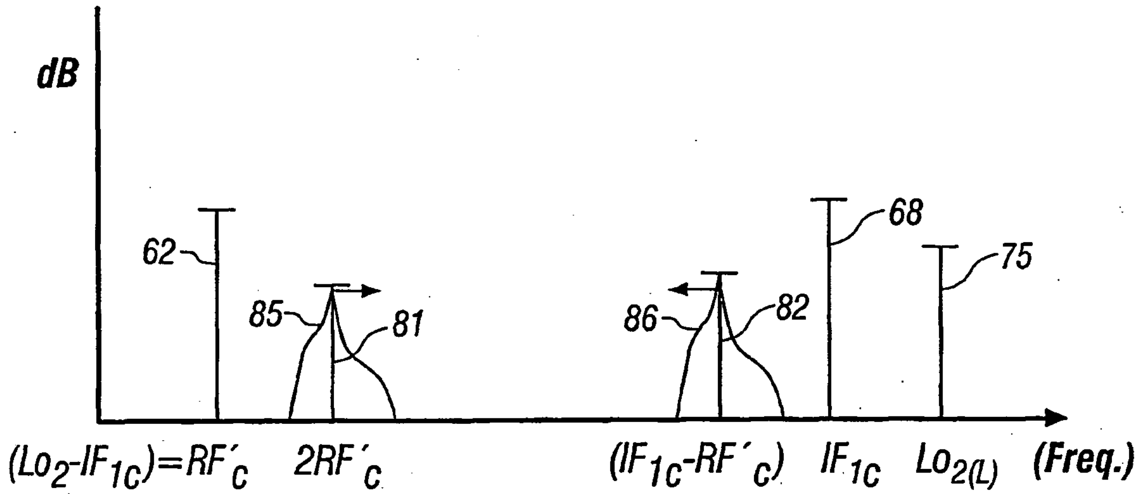


FIG. 7A
(Prior Art)

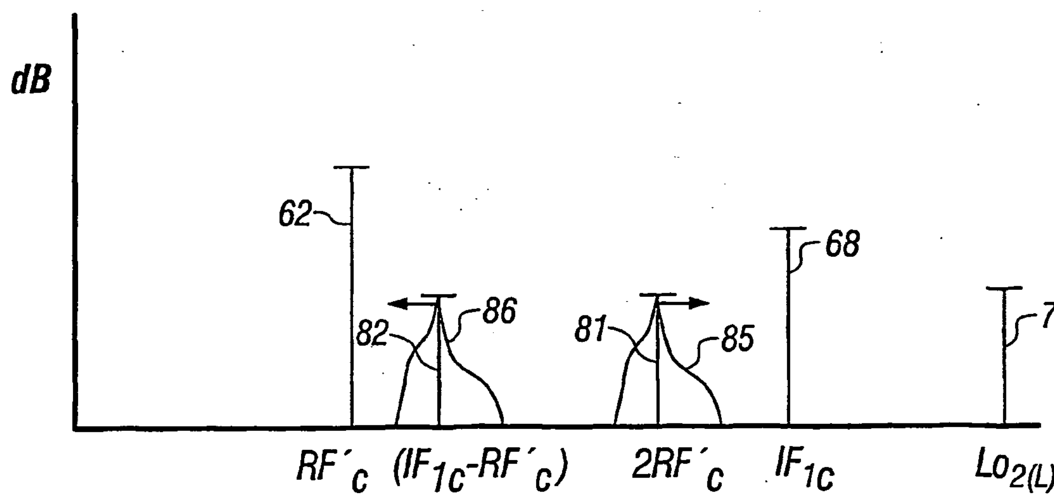


FIG. 7B
(Prior Art)

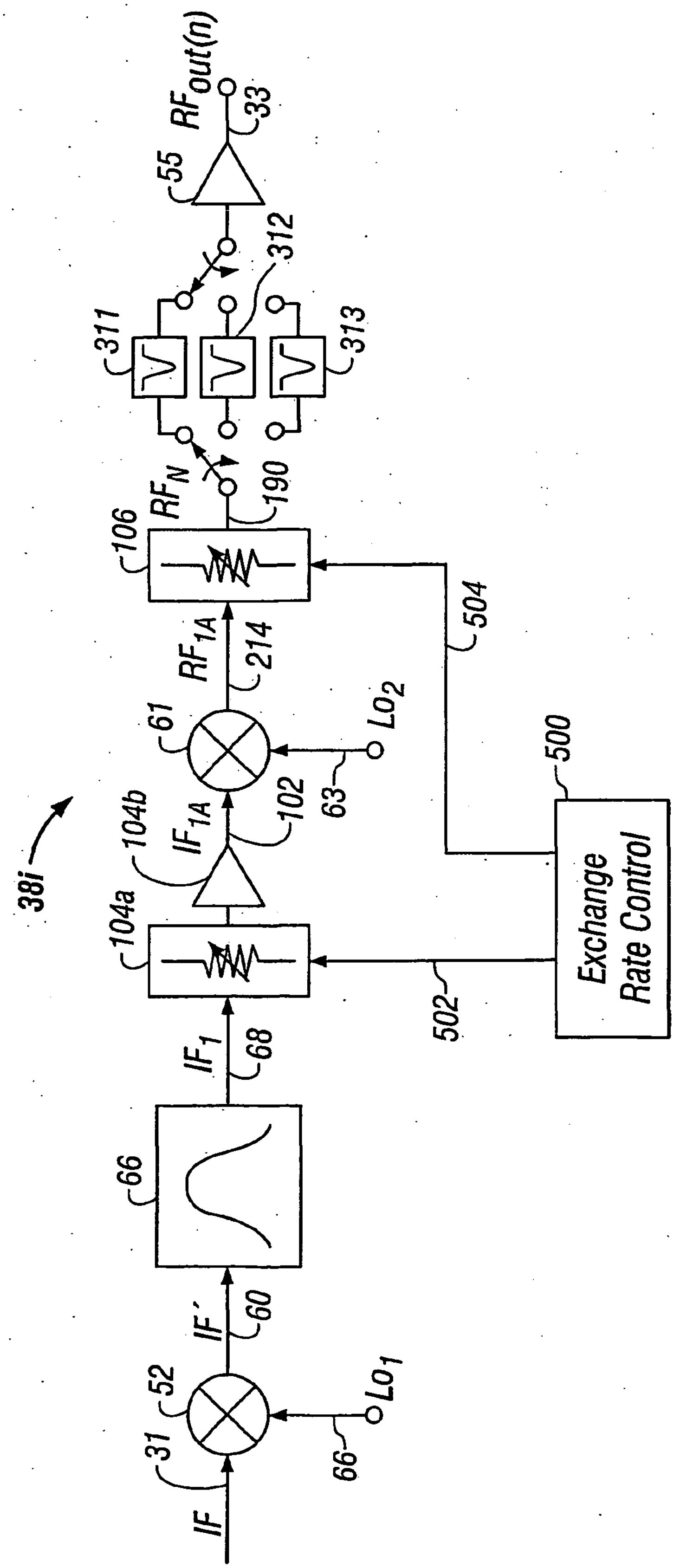

RFout(n)
33
55
312
311
313
RFN
190
106
504
RF1A
214
61
LO2
500
104b
IF1A
102
63
38i
104a
Exchange Rate Control
502
IF1
68
66
IF´
60
52
31
LO1
66
IF

FIG. 8

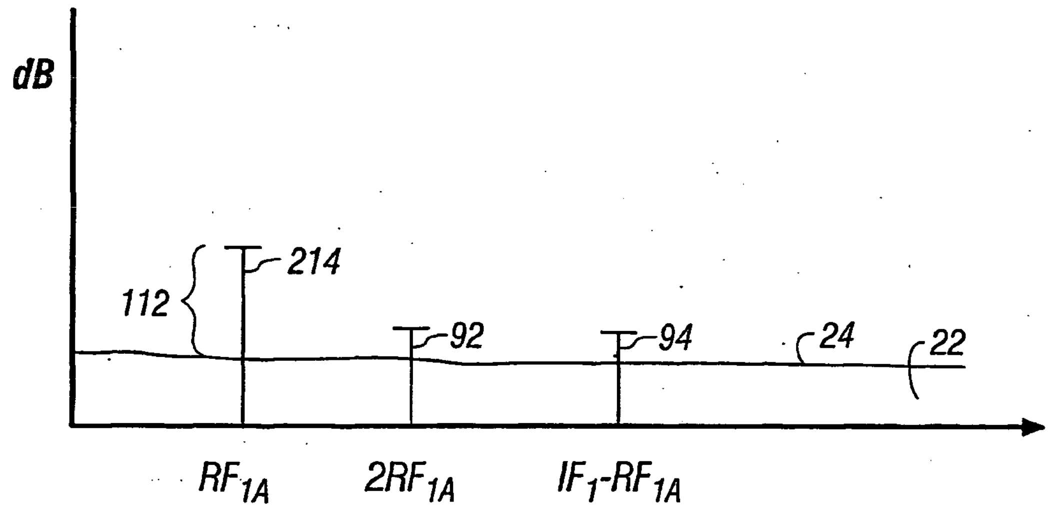


FIG. 9A

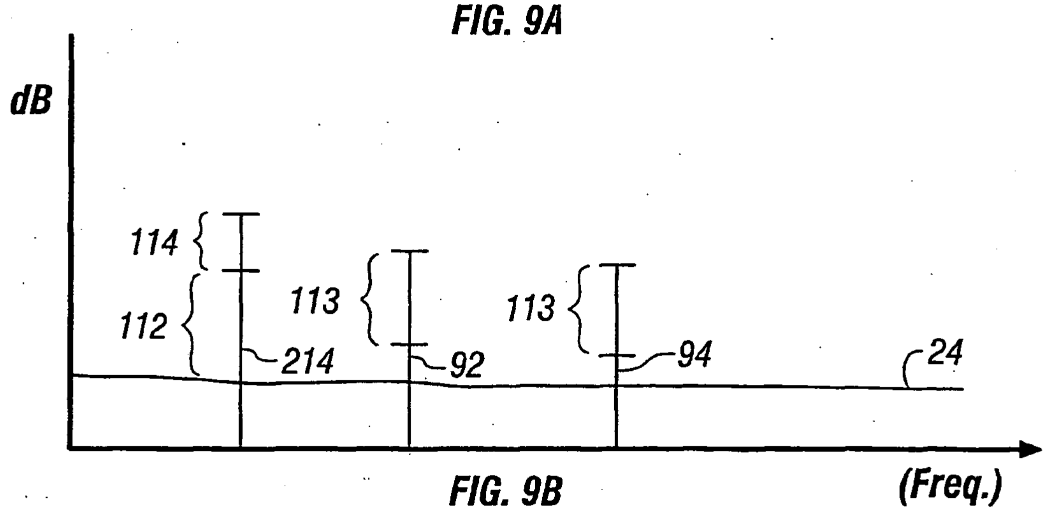


FIG. 9B

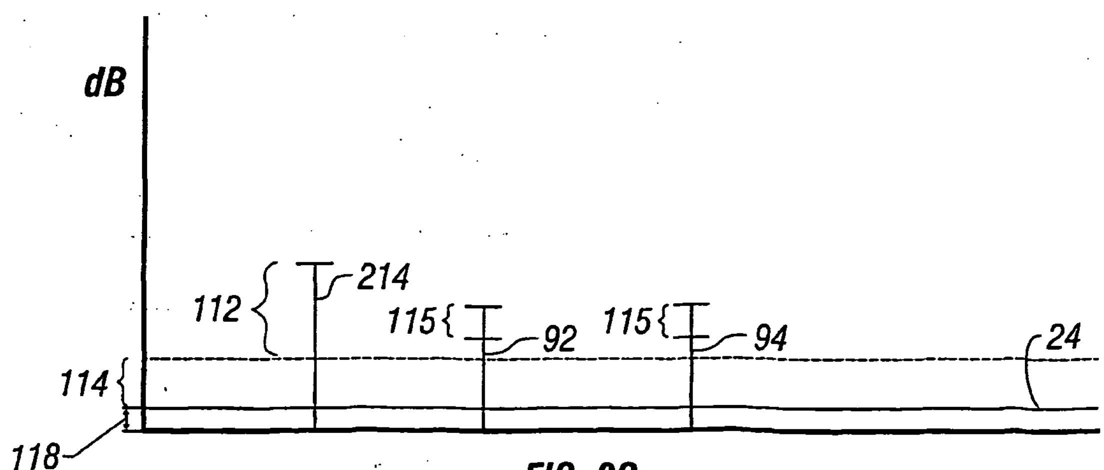


FIG. 9C

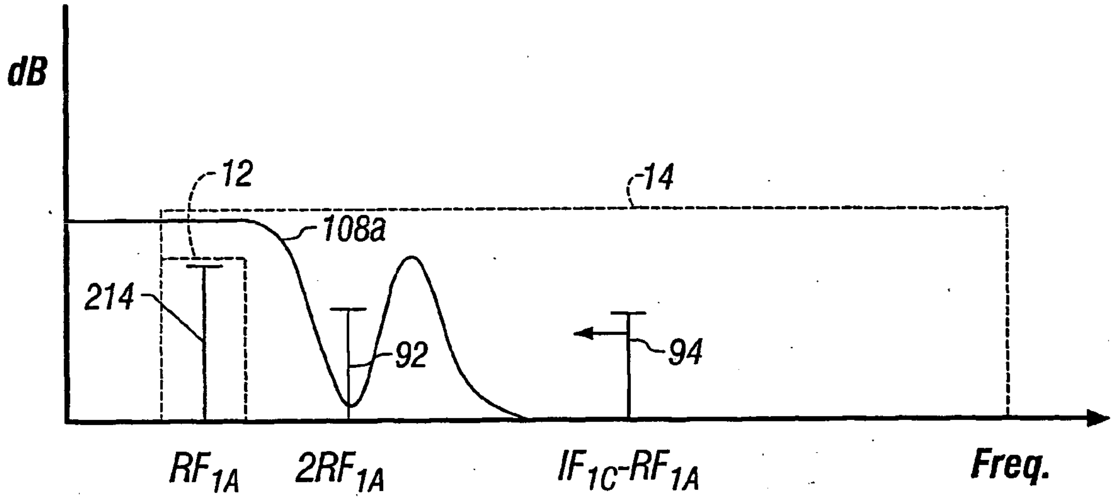


FIG. 10A

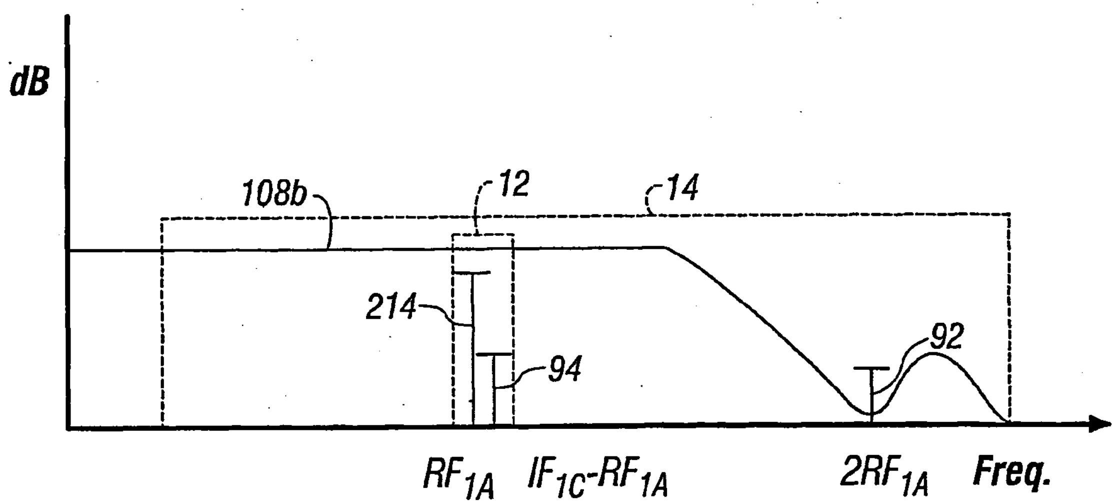


FIG. 10B

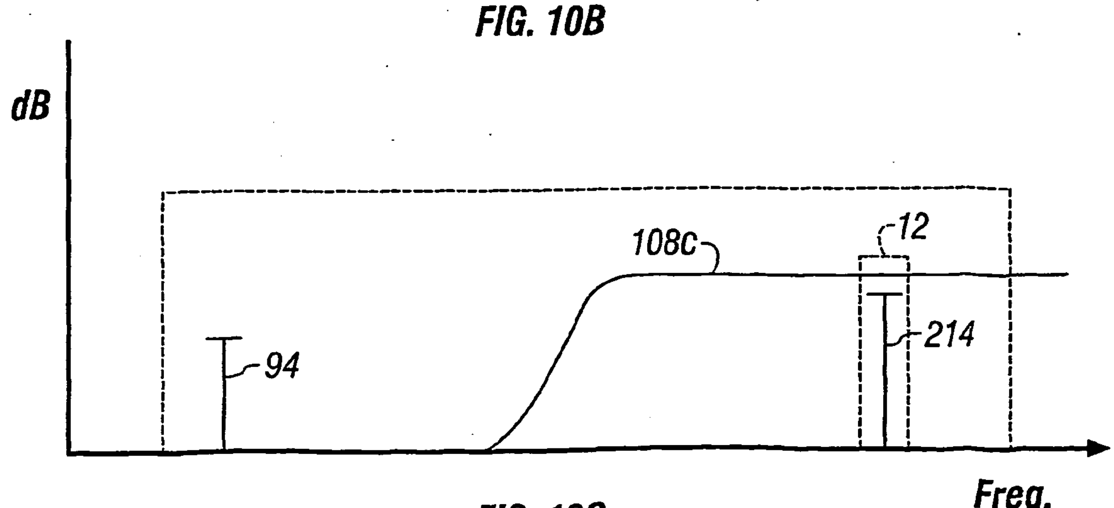


FIG. 10C

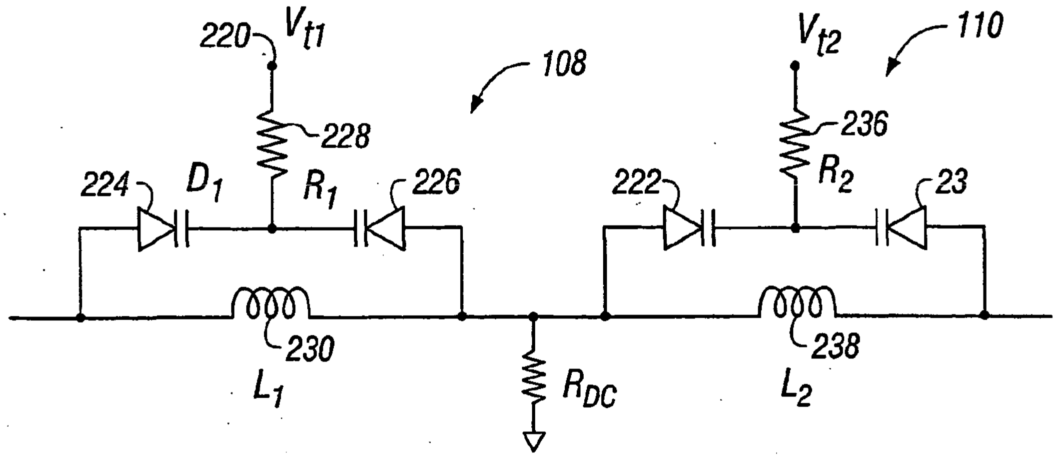


FIG. 11A

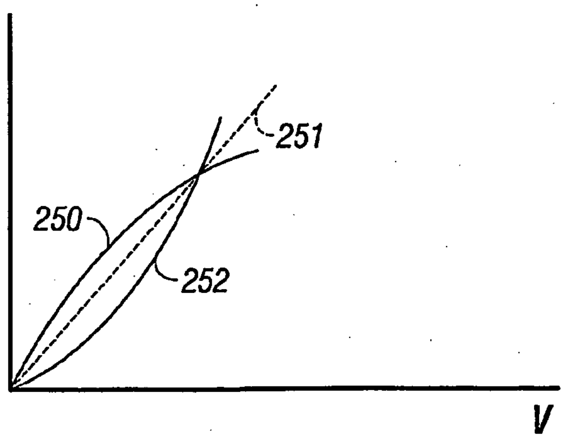


FIG. 11B

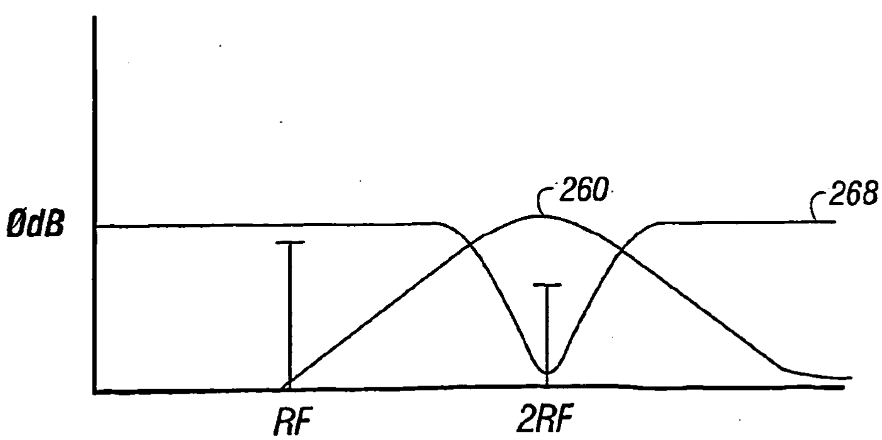


FIG. 11C

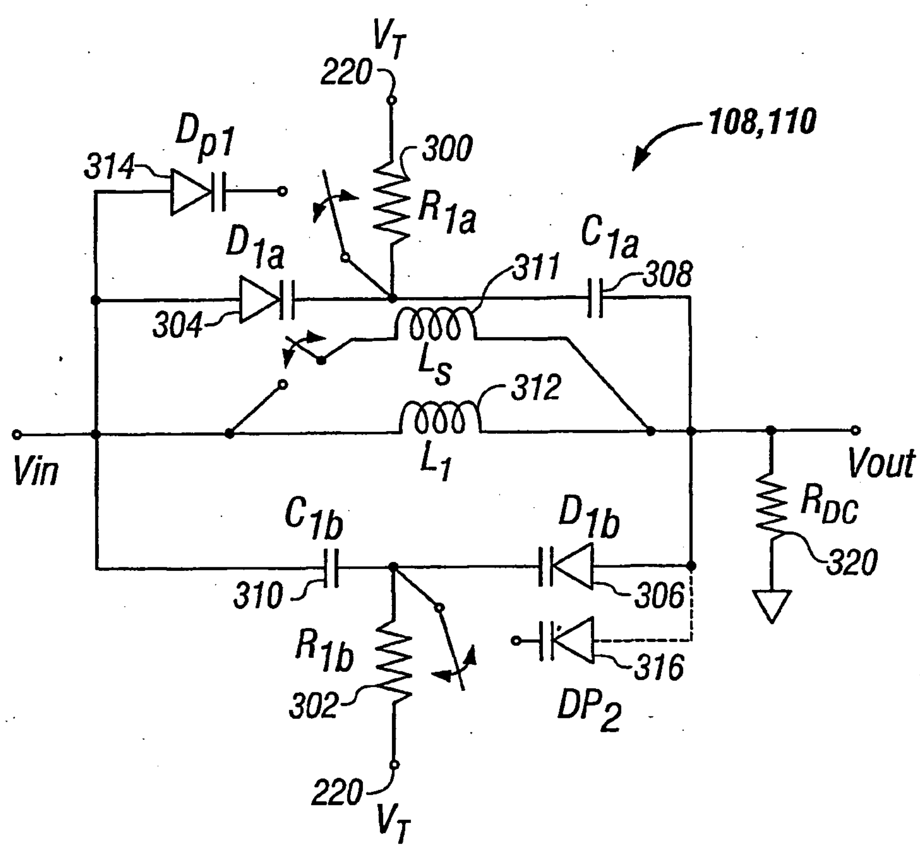
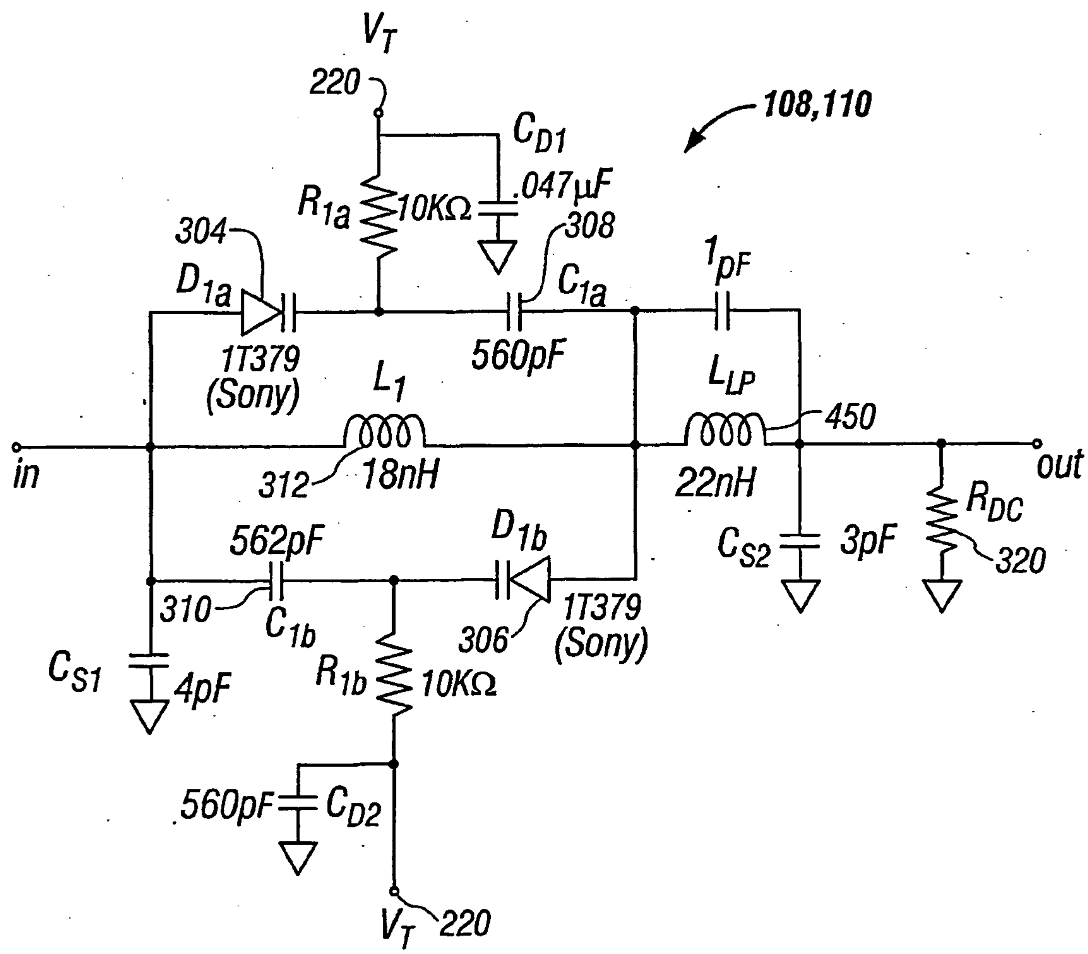

V_T
220
108,110
314
D_p1
300
R_1a
D_1a
311
C_1a
308
304
L_S
312
Vin
L_1
Vout
C_1b
D_1b
R_DC
320
310
306
R_1b
316
302
DP_2
220
V_T

FIG. 12



V_T
220
108,110
C_{D1}
.047μF
R_{1a}
10KΩ
304
308
D_{1a}
C_{1a}
1pF
1T379
(Sony)
560pF
L_1
L_{LP}
450
in
312
18nH
22nH
out
R_{DC}
562pF
D_{1b}
C_{S2}
3pF
320
310
C_{1b}
1T379
(Sony)
306
C_{S1}
4pF
R_{1b}
10KΩ
.560pF
C_{D2}
V_T
220

FIG. 13

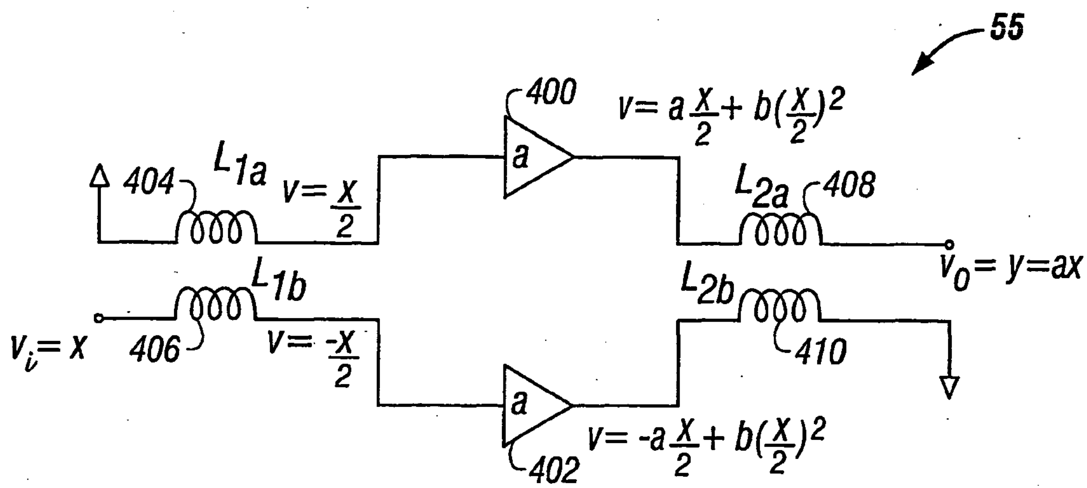


FIG. 14
(Prior Art)

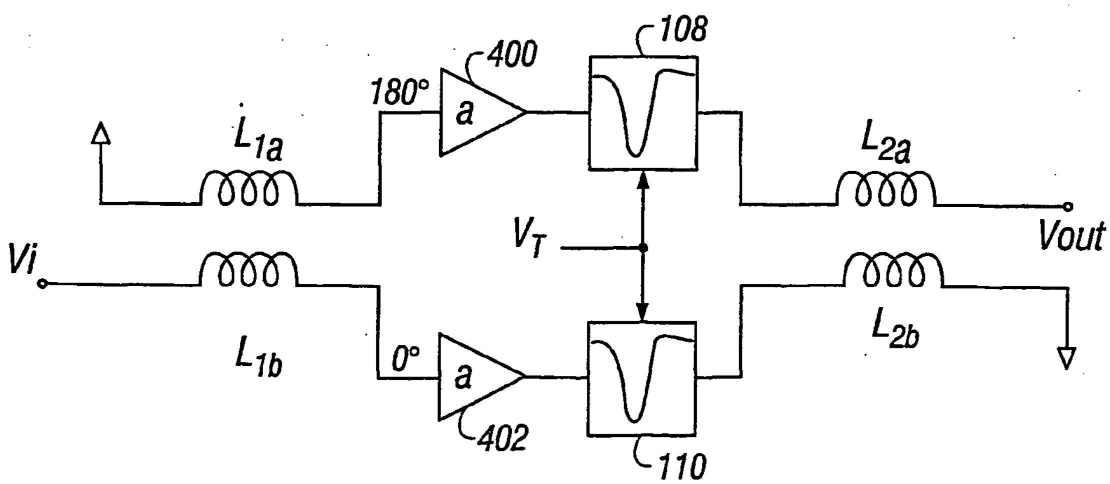


FIG. 15